



Defense Threat Reduction Agency  
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DTRA-TR-16-51

# TECHNICAL REPORT

## Quantifying Gamma/Neutron Discrimination in Gadolinium-Rich Real-time Neutron Detection Materials and Devices

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## UNIT CONVERSION TABLE

U.S. customary units to and from international units of measurement<sup>\*</sup>

U.S. Customary Units	<div style="display: flex; align-items: center; justify-content: center;"> <div style="margin-right: 10px;"> </div> Multiply by </div> <div style="display: flex; align-items: center; justify-content: center;"> <div style="margin-right: 10px;"> </div> Divide by<sup>†</sup> </div>	International Units
<b>Length/Area/Volume</b>		
inch (in)	2.54 × 10 <sup>-2</sup>	meter (m)
foot (ft)	3.048 × 10 <sup>-1</sup>	meter (m)
yard (yd)	9.144 × 10 <sup>-1</sup>	meter (m)
mile (mi, international)	1.609 344 × 10 <sup>3</sup>	meter (m)
mile (nmi, nautical, U.S.)	1.852 × 10 <sup>3</sup>	meter (m)
barn (b)	1 × 10 <sup>-28</sup>	square meter (m <sup>2</sup> )
gallon (gal, U.S. liquid)	3.785 412 × 10 <sup>-3</sup>	cubic meter (m <sup>3</sup> )
cubic foot (ft <sup>3</sup> )	2.831 685 × 10 <sup>-2</sup>	cubic meter (m <sup>3</sup> )
<b>Mass/Density</b>		
pound (lb)	4.535 924 × 10 <sup>-1</sup>	kilogram (kg)
unified atomic mass unit (amu)	1.660 539 × 10 <sup>-27</sup>	kilogram (kg)
pound-mass per cubic foot (lb ft <sup>-3</sup> )	1.601 846 × 10 <sup>1</sup>	kilogram per cubic meter (kg m <sup>-3</sup> )
pound-force (lbf avoirdupois)	4.448 222	newton (N)
<b>Energy/Work/Power</b>		
electron volt (eV)	1.602 177 × 10 <sup>-19</sup>	joule (J)
erg	1 × 10 <sup>-7</sup>	joule (J)
kiloton (kt) (TNT equivalent)	4.184 × 10 <sup>12</sup>	joule (J)
British thermal unit (Btu) (thermochemical)	1.054 350 × 10 <sup>3</sup>	joule (J)
foot-pound-force (ft lbf)	1.355 818	joule (J)
calorie (cal) (thermochemical)	4.184	joule (J)
<b>Pressure</b>		
atmosphere (atm)	1.013 250 × 10 <sup>5</sup>	pascal (Pa)
pound force per square inch (psi)	6.984 757 × 10 <sup>3</sup>	pascal (Pa)
<b>Temperature</b>		
degree Fahrenheit (°F)	[T(°F) - 32]/1.8	degree Celsius (°C)
degree Fahrenheit (°F)	[T(°F) + 459.67]/1.8	kelvin (K)
<b>Radiation</b>		
curie (Ci) [activity of radionuclides]	3.7 × 10 <sup>10</sup>	per second (s <sup>-1</sup> ) [becquerel (Bq)]
roentgen (R) [air exposure]	2.579 760 × 10 <sup>-4</sup>	coulomb per kilogram (C kg <sup>-1</sup> )
rad [absorbed dose]	1 × 10 <sup>-2</sup>	joule per kilogram (J kg <sup>-1</sup> ) [gray (Gy)]
rem [equivalent and effective dose]	1 × 10 <sup>-2</sup>	joule per kilogram (J kg <sup>-1</sup> ) [sievert (Sv)]

<sup>\*</sup> Specific details regarding the implementation of SI units may be viewed at <http://www.bipm.org/en/si/>.

<sup>†</sup> Multiply the U.S. customary unit by the factor to get the international unit. Divide the international unit by the factor to get the U.S. customary unit.

## **Objectives**

The objective of the proposed grant was to further explore our recently developed gadolinium-rich semiconducting materials by quantifying the responses to neutrons of these materials, alone and in simple device configurations. Both modeling and laboratory experiments were to supply the data for evaluating the performance of these materials and devices and results of each were to be compared with independently obtained data.

## **Status of Effort**

The primary focus was on modeling, as well as to guide efficient laboratory experimentation for verification of previous and additional data. Modeling with MCNPX was begun to evaluate material and device performance. Progress was made in performing sensitivity analysis, code validation protocols, and reliability assessment, if the input data was verified and reliable. Design of the experimental protocols for materials characterization and testing device radiation responses was initiated. Data was collected on usability of radiation detection devices in field situations. As indicated in new findings (below), the unexplained variability and irreproducibility of previous data from other laboratories curtailed further efforts.

## **New Findings**

Unfortunately, there were apparently deficiencies in some of the data verification protocols in some of the preliminary reports from laboratories not under the direct supervision of Dr. Brand or Dr. Hallbeck. Attempts to reproduce that crucial data were unsuccessful, as were attempts to clarify the analysis or pedigree of that data with the laboratories from which it came. It appeared as if there may have been some methods error in the collection and interpretation of the data, as well as possible withholding and misrepresentation by former collaborators.

Without reliable data, the input for the modelling contained too much variability for the PIs to proceed with confidence. With greater institutional support, the PIs might have been able to obtain verified, reliable data from their own laboratories and from new, independent sources so that the work could have moved forward.

The positive results of the work are that the supercritically-grown cubic gadolinium oxide has shown neutron response which may yet hold potential for radiation detection. In addition, some baseline end-use requirements of radiation detection parameters for field deployment have been published.

## **Personnel**

Jennifer I. Brand and M. Susan Hallbeck, PIs.

Affiliated personnel: P. A. Savory, L. Carlson, P. C. Skidmore, J. V. Crowe, J. Applebee

## **Publications**

Two publications resulted from this work:

1. Savory, P.A., Skidmore, P.C., Crowe, J.V. and Hallbeck, M.S. (2013). Exploring first responder preferences and opinions about handheld radiation detectors. *International Journal of Industrial and Systems Engineering*. In Press.
2. Savory, P.A., Crowe, J.V. and Hallbeck, M.S. (2012). Focus group analysis of hand-held radiation detector design. *International Journal of Industrial Ergonomics*, 42(1), 17-24.

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